described. An outline of the experiment is illustrated in Fig. 3. Sample leads 4 were formed by plating lead-free materials of Sn, Sn-Bi, Sn-Zn and Sn-Ag alloys, respective which are considered to be usable as alternative materials for the the conventional Sn-10 Pb alloy layer, onto leads each of which is an electrode made of an Fe-Ni alloy (42 alloy). Besides, an evaluation was also performed for combinations with the conventional Sn-10 Pb alloy plating. The respective example lead 4 was 3 mm wide and 38 mm long. It was bent to form right angles so that the length of the soldering section is 22 mm. The plating thickness was approximately 10 μm for each composition. The respective example lead 4 was soldered to a Cu pad (Cu electrode) 7 on a glass epoxy substrate 6, which is a circuit board, with utilization of a lead-free solder 5 of a 82.2 wt% Sn-2.8 wt% Ag-15 wt% Bi alloy (hereinafter referred to as Sn-2.8Ag-15Bi).

The Cu pad (Cu electrode) 7 on the glass epoxy substrate 6 had a size of 3.5 mm × 25 mm. The solder 5 was provided in the form of a foil of 0.1 mm × 25 mm × 3.5 mm. More specifically, the solder foil 5 was placed on the Cu pad 7 on the glass epoxy substrate 6 and the example lead 4 being bent with the right angle was placed on the solder foil 5. Soldering was performed in the air at a maximum temperature of 220°C after preheating at 140°C for 60 seconds. A rosin flux containing chlorine was used when soldering. After

soldering, cleaning was conducted with an organic solvent. The pull test was conducted in three cases; i.e., a sample lead immediately after soldering, another example lead exposed to a high temperature of 125°C for 168 hours after soldering taking account of the deterioration of bonding strength due to a change with the passage of time, and a further sample lead after soldering following the exposure thereof to 150°C for 168 hours to investigate bonding strength in the case where wettability of lead is deteriorated. In the pull test, the example lead was pulled vertically at a rate of 5 mm/minute by gripping its distal end while the substrate is fixed. Then a maximum strength and a generally saturated constant strength were detected as a fillet strength and a flat portion strength, respectively, for the example lead of each composition. The test was conducted ten times for each condition to determine an average value.

The test results of the fillet strength of the example lead of each composition are shown in Fig. 4. In plastic package devices such as ordinary QFP-LSIs, it is necessary that fillet strength be at least approximately 5 kgf in consideration of a difference in thermal expansion coefficient of printed-circuit board. From this, it became apparent that an adequate bonding interface cannot be obtained in the case of Sn-Zn, Sn-Ag and Sn-Pb alloy layers although fillet strength of not less than 5 kgf was

obtained with the example leads in which an Sn layer or Sn-Bi layers other than Sn-23Bi layers containing 23 wt% Bi are plated on the Fe-Ni alloy (42 alloy). In addition to these example leads, further three types of example leads were prepared by providing an Ni plating layer having a thickness of about 2 μm onto the 42 alloy and plating the Ni layer with Au layer, a Pd layer, and a Pd layer with a further Au layer, respectively. Soldering was performed in the same manner and bonding strength was investigated. However, enough fillet strength was incapable of being obtained as shown in Fig. 4. Accordingly, it became apparent that it is necessary to apply an Sn-Bi layer to a lead of an electrode.

Wettability to the Sn-2.8Ag-15Bi solder was tested by the meniscograph method in the Sn-Bi alloy plated leads which showed enough bonding strength in the above pull test conducted on example leads of various compositions. A flux of less activity was used in order to investigate wettability. Test pieces were obtained by cutting the above example leads into a length of 1 cm. The wettability test was conducted under the test conditions: a solder bath temperature of 220°C, an immersion speed of 1 mm/minute, an immersion depth of 2 mm and an immersion time of 20 seconds. The time which elapses till the load recovers to 0 (zero) was regarded as wetting time and the load after immersion for 20 seconds was regarded as wetting force.